# Branching fractions and charge asymmetries in charmless hadronic $B$ decays at *BABAR*

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**Abstract**

We present measurements of branching fraction, polarization and charge asymmetry in charmless hadronic $B$ decays with $\eta$, $\eta'$, $\omega$, and $b_1$ in the final state. All the results use the final *BABAR* dataset.

## 1 Introduction

Experimental measurements of branching fraction, polarization and $CP$-violating charge asymmetries in rare $B$ decays are important tests of the Standard Model (SM) and its extensions. Several predictions are available for these quantities, using different theoretical approaches [1, 2]. All these quantities may provide sensitivity to the presence of heavy non-SM particles in the loop diagrams.

The large branching fraction difference between $\eta' K$ and $\eta K$ seems to be explained in the SM contest [3]. Rates of the decay modes to $\eta\eta$, $\eta\phi$, $\eta'\ \eta'$, and $\eta'\phi$ are used in flavor SU(3)-based calculations [2, 4], to constraint the unsigned difference between the $CP$-violating parameter $S$ measured in $\eta' K^0$ and $\phi K^0$ and $\sin 2\beta$ measured in $J/\psi K^0$. The charge asymmetry $\mathcal{A}_{ch}$ is expected to be sizable in $\eta K^+$ and suppressed in $\eta' K^+$ decays [2].

In $B \to VV$ decays (where $V$ is a vector), simple helicity arguments predict a longitudinal polarization fraction $f_L$ close to 1. In 2003 both *BABAR* and Belle measured $f_L \sim 0.5$ in $B \to \phi K^*(892)$ [5]. Possible explanations for this puzzle have been proposed within the SM [6] and in new physics scenarios [7].

## 2 Analysis Technique

Results shown in this paper are based on a sample of $465 \times 10^6$ $B\overline{B}$ pairs collected at a center-of-mass energy $\sqrt{s}$ equal to the mass of the $\Upsilon(4S)$ resonance at the PEP-II asymmetric $e^+e^-$ collider, at the SLAC National Accelerator Laboratory, and recorded by the *BABAR* detector [8].

$B$ meson is reconstructed into $\eta\pi^+$, $\eta K$, $\eta\eta$, $\eta\omega$, $\eta\phi$, $\eta'\pi^+$, $\eta' K$, $\eta'\eta'$, $\eta'\omega$, $\eta'\phi$, $\omega K^*$, $\omega f_0(600)$, $\omega\rho$, $b_1 K^*(892)$, and $b_1\rho$ final states. In $\omega K^*$, we consider either $K^*(892)$, $(K\pi)_0$, and $K_2^*(1430)$. The $B$ meson is kinematically characterized by $\Delta E \equiv E_B - \frac{1}{2}\sqrt{s}$ and $m_{\rm ES} \equiv \sqrt{s/4 - \vec{p}_B^{\,2}}$, where $(E_B, \vec{p}_B)$ is the $B$ meson four-momentum vector expressed in $\Upsilon(4S)$ rest frame.

Background arises primarily from random combinations of particles in $e^+e^- \to q\overline{q}$ events ($q = u, d, s, c$). We suppress this background with requirements on event shape variables and on the energy, invariant mass and particle identification signature of the decay products. For $VV$, and vector-tensor $VT$ decays, we define the helicity angles $\theta_1$ and $\theta_2$, where the subscript refers to $B$ daughters. For two (three) body decay, $\theta_i$ is defined as the angle between the direction of the recoiling $B$ and the direction of one of the resonance daughters (the normal to the plane identified by the daughter decay products).

For each mode, results are obtained from extended maximum likelihood fits with input variables $\Delta E$, $m_{\rm ES}$, and the output of a Fisher discriminant that combines different event shapes variables.

Where useful, the masses of $B$ daughters are included in the fit. In $\omega K^*$ and $\omega\rho$, $f_L$ and $f_T = 1 - f_L$ are extracted using the knowledge of the decay angular distribution:

$$\frac{\mathrm{d}\Gamma}{\mathrm{dcos}\,\theta_1 \mathrm{dcos}\,\theta 2} = \begin{cases} f_T \sin^2\theta_1 \sin^2\theta_2 + 4 f_L \cos^2\theta_1 \cos^2\theta_2 & \text{for } B \to VV \\ f_T \sin^2\theta_1 \sin^2\theta_2 \cos^2\theta_2 + \frac{f_L}{3}\cos^2\theta_1 (3\cos^2\theta 2 - 1)^2 & \text{for } B \to VT \end{cases} \tag{1}$$

# 3 Results

In Table 1 we report the branching fraction $\mathcal{B}$ and the $\mathcal{B}$ upper limit (UL) at 90% confidence level (CL), the significance $S$ (with systematic uncertainties included), the charge asymmetry $\mathcal{A}_{ch}$, and $f_L$, for each decay mode [9]. The first error is statistical and second systematic. Results for modes

Table 1: Results for modes presented in this paper .

| Decay Mode | $\mathcal{B}$ $(10^{-6})$ | $\mathcal{B}$ UL $(10^{-6})$ | $S$ $(\sigma)$ | $A_{ch}$ | $f_L$ |
|---|---|---|---|---|---|
| $\eta\pi^+$ | $4.00 \pm 0.40 \pm 0.24$ | – | – | $-0.03 \pm 0.09 \pm 0.03$ | – |
| $\eta K^0$ | $1.15^{+0.43}_{0.38} \pm 0.09$ | 1.8 | 3.5 | – | – |
| $\eta K^+$ | $2.94^{+0.39}_{-0.34} \pm 0.21$ | – | – | $-0.36 \pm 0.11 \pm 0.03$ | – |
| $\eta\eta$ | $0.5 \pm 0.3 \pm 0.1$ | 1.0 | 1.9 | – | – |
| $\eta\omega$ | $0.94^{+0.35}_{-0.30} \pm 0.09$ | 1.4 | 3.7 | – | – |
| $\eta\phi$ | $0.2 \pm 0.2 \pm 0.1$ | 0.5 | 1.4 | – | – |
| $\eta'\pi^+$ | $3.5 \pm 0.6 \pm 0.2$ | – | – | $+0.03 \pm 0.17 \pm 0.02$ | – |
| $\eta' K^0$ | $68.5 \pm 2.2 \pm 3.1$ | – | – | – | – |
| $\eta' K^+$ | $71.5 \pm 1.3 \pm 3.2$ | – | – | $+0.008^{+0.017}_{-0.018} \pm 0.009$ | – |
| $\eta'\eta'$ | $0.6^{+0.5}_{-0.4} \pm 0.4$ | 1.7 | 1.0 | – | – |
| $\eta'\omega$ | $1.01^{+0.46}_{-0.38} \pm 0.09$ | 1.8 | 3.6 | – | – |
| $\eta'\phi$ | $0.2 \pm 0.2 \pm 0.3$ | 1.1 | 0.5 | – | – |
| $\omega K^*(892)^0$ | $2.2 \pm 0.6 \pm 0.2$ | – | 4.1 | $+0.45 \pm 0.25 \pm 0.02$ | $0.72 \pm 0.14 \pm 0.02$ |
| $\omega K^*(892)^+$ | $2.4 \pm 1.0 \pm 0.2$ | 3.8 | 2.5 | $+0.29 \pm 0.35 \pm 0.02$ | $0.41 \pm 0.18 \pm 0.05$ |
| $\omega(K\pi)^{*0}_0$ | $18.4 \pm 1.8 \pm 1.7$ | – | 9.8 | $-0.07 \pm 0.09 \pm 0.02$ | – |
| $\omega(K\pi)^{*+}_0$ | $27.5 \pm 3.0 \pm 2.6$ | – | 9.2 | $-0.10 \pm 0.09 \pm 0.02$ | – |
| $\omega K_2(1430)^{*0}$ | $10.1 \pm 2.0 \pm 1.1$ | – | 5.0 | $-0.37 \pm 0.17 \pm 0.02$ | $0.45 \pm 0.12 \pm 0.02$ |
| $\omega K_2(1430)^{*+}$ | $21.5 \pm 3.6 \pm 2.4$ | – | 6.1 | $+0.14 \pm 0.15 \pm 0.02$ | $0.56 \pm 0.10 \pm 0.04$ |
| $\omega f_0$ | $1.0 \pm 0.3 \pm 0.1$ | 1.5 | 4.5 | – | – |
| $\omega\rho^0$ | $0.8 \pm 0.5 \pm 0.2$ | 1.6 | 1.9 | – | 0.8 fixed |
| $\omega\rho^+$ | $15.9 \pm 1.6 \pm 1.4$ | – | 9.8 | $-0.20 \pm 0.09 \pm 0.02$ | $0.90 \pm 0.05 \pm 0.03$ |
| $b_1^0\rho^0$ | $-1.1 \pm 1.7^{+1.4}_{-0.9}$ | 3.4 | – | – | – |
| $b_1^-\rho^+$ | $-1.8 \pm 0.5 \pm 1.0$ | 1.4 | – | – | – |
| $b_1^0\rho^+$ | $-3.0 \pm 0.9 \pm 1.8$ | 3.3 | – | – | – |
| $b_1^+\rho^0$ | $1.5 \pm 1.5 \pm 2.2$ | 5.2 | 0.4 | – | – |
| $b_1^0 K^*(892)^0$ | $4.8 \pm 1.9^{+1.5}_{-2.2}$ | 8.0 | 2.0 | – | – |
| $b_1^- K^*(892)^+$ | $2.4^{+1.5}_{-1.3} \pm 1.0$ | 5.0 | 1.7 | – | – |
| $b_1^0 K^*(892)^+$ | $0.4^{+2.0+3.0}_{-1.5-2.6}$ | 6.7 | 0.1 | – | – |
| $b_1^+ K^*(892)^0$ | $2.9 \pm 1.5 \pm 1.5$ | 5.9 | 1.5 | – | – |

containing $\eta$ or $\eta'$ meson in the final states are preliminary. Significance is taken as $\sqrt{-2\ln \mathcal{L}_{max}/\mathcal{L}_0}$, where $\mathcal{L}_{max}$ ($\mathcal{L}_0$) is value of the likelihood at its maximum (for zero signal). If the significance is smaller than $5\sigma$, we calculate a Bayesian UL at 90% CL, integrating the likelihood in the positive branching fraction region. For the well established decay modes $\eta K^+$, $\eta' K^0$, and $\eta^{(\prime)}\pi^+$ we do not report the significance. In $\omega K^*(892)^+$ with $K^*(892)^+ \to K^0_S\pi^+$, $f_L$ is fixed to 0.5 in the fit. Main contributions of systematic uncertainties to branching fraction come from fit bias and uncertainties in

the probability density functions parameterization. The $B \to \eta' K$ decay mode is systematic limited due to the uncertainties on daughter branching fractions.

## 4 Conclusions

We reported measurements for several charmless hadronic $B$ decays. In $B \to \eta K^+$ we find evidence of direct *CP* violation at $3.3\sigma$ level. $B \to \omega (K\pi)^*_0$ and $B \to \omega K^*_2(1430)$ decays are observed for the first time. $f_L$ in $B^+ \to \omega K^*(892)^+$ and $B^+ \to \omega \rho^+$ is consistent with 0.5 and 1, respectively, as expected by theoretical predictions [6]. $f_L$ in $B \to \omega K^*_2(1430)$ is consistent with 0.5 in disagreement with $f_L(\phi K^*_2(1430)) \sim 1$ [10]. No theoretical predictions are available for these modes. Results in $B \to b_1 \rho$ and $B \to b_1 K^*$ are in disagreement with and seem to be systematically lower than theoretical predictions [1].

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